In re Patent Application of: Tadashi Ishikawa et al.

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For: LARGE-HEAT-INPUT BUTT WELDED JOINTS HAVING EXCELLENT BRITTLE FRACTURE RESISTANCE

TRANSLATOR'S DECLARATION

Honorable Commissioner of Patents & Trademarks
Washington, D.C. 20231

Sir:

I, Masaki Honda , residing at c/o SEIWA PATENT & LAW, Toranomon 37 Mori Bldg., 3-5-1, Toranomon Minato-ku, Tokyo 105-8423, Japan declare the following:

(1) That I know well both the Japanese and English languages;

(2) That I translated Japanese Patent Application No. 2003-362122 , filed October 22, 2003 , from the Japanese language to the English language;

(3) That the attached English translation is a true and correct translation of the aforesaid Japanese Patent Application No. 2003-362122 to the best of my knowledge and belief; and

(4) That all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements are made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and that such false statements may jeopardize the validity of the application or any patent issuing thereon.

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Date

Masaki Honda
Translator Masaki Honda

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[INVENTOR]
[Address or Residence] c/o NIPPON STEEL CORPORATION Technical Development Bureau, 20-1, Shintomi, Futtsu-shi, Chiba
[Name] Tadashi Ishikawa

[INVENTOR]
[Address or Residence] c/o NIPPON STEEL CORPORATION Technical Development Bureau, 20-1, Shintomi, Futtsu-shi, Chiba
[Name] Takehiro Inoue

[INVENTOR]
[Address or Residence] c/o NIPPON STEEL CORPORATION Technical Development Bureau, 20-1, Shintomi, Futtsu-shi, Chiba
[Name] Hiroshi Shimanuki

[INVENTOR]
[Address or Residence] c/o NIPPON STEEL CORPORATION Technical Development Bureau, 20-1, Shintomi, Futtsu-shi, Chiba
[Name] Tadashi Koseki

[INVENTOR]
[Address or Residence] c/o NIPPON STEEL CORPORATION OITA WORKS, 1, Oaza Nishinosu, Oita-shi, Oita
[Name] Jun Ootani

[INVENTOR]
[Address or Residence] c/o NIPPON STEEL CORPORATION OITA WORKS, 1, Oaza Nishinosu, Oita-shi, Oita
[Name] Masanori Minagawa

[INVENTOR]
[Address or Residence] c/o NIPPON STEEL CORPORATION Technical Development Bureau, 20-1, Shintomi, Futtsu-shi, Chiba
[Name] Akihiko Kojima

[APPLICANT]
[Identification Number] 000006655
[Name of Applicant] NIPPON STEEL CORPORATION

[PATENT ATTORNEY]
[Identification Number] 100099759
[Patent Attorney]
[Name of Patent Attorney] Atsushi Aoki
[Phone Number] 03-5470-1900

[APPOINTED PATENT ATTORNEY]
[Identification Number] 100077517
[Patent Attorney]
[Name of Patent Attorney] Takashi Ishida

[APPOINTED PATENT ATTORNEY]
[Identification Number] 100087413
[Patent Attorney]
[Name of Patent Attorney] Tetsuji Koga

[APPOINTED PATENT ATTORNEY]
[Identification Number] 100113918
[Patent Attorney]
[Name of Patent Attorney] Hiroshi Kamematsu

[APPOINTED PATENT ATTORNEY]
[Identification Number] 100082898
[Patent Attorney]
[Name of Patent Attorney] Masaya Nishiyama

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[Name of Article] Specification 1
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[NAME OF DOCUMENT] SCOPE OF CLAIM FOR PATENT

[Claim 1]

A large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, is characterized by:

(a) the hardness of the weld metal is not less than 70% and not more than 110%, and

(b) the width of the weld metal is not more than 70% of the plate thickness of the base metal.

[Claim 2]

A large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, is characterized by:

(a) the hardness of the weld metal is not less than 70% and not more than 110%,

(b) the width of the weld metal is not more than 70% of the plate thickness of the base metal, and

(c) the wideness of the region affected by welding whose hardness is softened to not more than 95% of the hardness of the base metal unaffected by heat has a width of not less than 5 mm.

[Claim 3]

A large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, is characterized by:

(a) the hardness of the weld metal is not less than 70% and not more than 110%,

(c) the wideness of the region affected by welding whose hardness is softened to not more than 95% of the hardness of the base metal unaffected by heat has a width of not less than 5 mm, and

(d) the prior austenite austenite grain size in the heat-affected zone contacting the welding fusion line is not more than 200 μm.

[Claim 4]

A large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, is characterized by:

(a) the hardness of the weld metal is not less than 70% and not more than 110%,

(b) the width of the weld metal is not more than 70% of the plate thickness of the base metal,

(c) the wideness of the region affected by welding whose hardness is softened to not more than 95% of the hardness of the base metal unaffected by heat has a width of not less than 5 mm, and

(d) the prior austenite austenite grain size in the heat-affected zone contacting the welding fusion line is not more than 200 μm.

[Claim 5]

The large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, according to any one of claims 1 to 4, which is prepared by butt-welding high-strength steel plates over 50 mm in thickness.

[NAME OF DOCUMENT] Specification

[Title of the Invention] LARGE-HEAT-INPUT BUTT WELDED JOINTS HAVING EXCELLENT BRITTLE FRACTURE RESISTANCE

[Technical Field]

[0001]

The present invention relates to a large-heat-input butt-weld joints having excellent brittle fracture resistance in welded structures and, particularly, those made by butt-welding steel plates having thickness greater than 50 mm.

[Background Art]

[0002]

In welded structures, fractures are mostly likely to occur in welded joints. There are several reasons. One is that welding defects that occur during welding become stress concentrations where fractures start. Another reason is that welding heat coarsens the microstructure of steel plates and, as a result, lowers the fracture toughness Kc that is used as a measure of brittle fracture resistance in welded joints.

[0003]

In order to prevent deformation and stress concentration in welded joints, it is a basic requirement, in forming welded joints, to make the strength and hardness of the weld metal higher than those of the base metal. That is to say, welded joints are designed to have greater strength than the base metal.

[0004]

Fracture toughness of welded joints is evaluated by a deep notch test that pulls, in the directions indicated by arrows, a test specimen having a 240 mm long notch machined is assumedly the most weak part of welded joint in the middle of a 400 mm width specimen having a weld metal at the center thereof.

[0005]

Conventionally fracture toughness of welded joints in steel plates for ship structures not more than 50 mm thick have been evaluated by this test and the performance and

characteristics required of steel plates for ship construction have been considered.

[0006]

Steel plates for ship construction having excellent brittle fracture and fatigue characteristics (TMCP steel plates) have been developed by considering the fracture toughness of welds (such as one disclosed in Patent Document 1).

[0007]

TMCP or other similar steel plates approximately 50 mm in thickness have been used for the construction of large tankers and container ships of not more than 6,000 TEU. As construction needs for container ships larger than 6,000 TEU have increased, steel plates 60 mm thick or more are being used.

[0008]

While the upper limit of yield strength of steel plates for ship construction presently in use is approximately 390 MPa, thicker steel plates (such as those thicker than 50 mm) will be used as the size of container ships grows larger. When the thickness of steel plates increases too much, the number of man-hour of welding operations increases to cause industrial problems such as an increase in construction cost and an increase in the weight of the container ships.

[0009]

[Patent Document 1] Japanese Unexamined Patent Publication No. 06-88161

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0010]

As the size of container ships and other welded structures increases, it is now desired to construct container ships exceeding 6,000 TEU by using high-tensile steel plates that are over 50 mm in thickness and have high design stresses.

[0011]

The inventors investigated performances of large-heat-input welded joints prepared by butt welding steel plates not less than 50 mm thick since the fractures are mostly likely to occur in welded joints.

[0012]

The investigation led to a finding that large-heat-input welded joints prepared by butt welding steel plates not less than 50 mm thick do not always shown good fracture toughness Kc in the large-scale deep-notch test, though they shown good results in the small-scale V-notch Charpy impact test.

[0013]

Therefore, the object of the present invention is to provide, based on the above finding, welded joints having sufficiently high fracture toughness Kc by butt welding high-strength steel plates for welded ship construction having thickness greater than 50 mm and yield strength of the 460 MPa class.

[0014]

In order to achieve the above object, the inventors investigated the mechanical properties of base metals and welded joints. In order to prevent deformation and stress concentration in welded joints, the inventors found a new joint design technology that choose weld metals whose strength and hardness are greater than those of base metals in a break of conventional welded joint designs.

[0015]

The inventors discovered that the lowering of joint strength by undermatching in the design of large-heat-input butt-welded joints can be prevented by controlling the hardness of the weld metal to not less than 70% and not more than 110% of the hardness of the base metal (that is, joint design by undermatching) and controlling the width of the weld metal to not more than 70% of the plate thickness of the base metal.

[0016]

The inventors completed the present invention that

provides a technology to provide welded joints having high fracture toughness Kc by welding with large-heat-input high-strength steel plates having yield strength of the 460 MPa class and thickness greater than 50 mm (preferably between over 50 mm and approximately 70 mm).

[0017]

The gist of the present invention us as described below.

[0018]

(1) A large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, is characterized by:

(a) the hardness of the weld metal is not less than 70% and not more than 110%, and

(b) the width of the weld metal is not more than 70% of the plate thickness of the base metal.

[0019]

(2) A large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, is characterized by:

(a) the hardness of the weld metal is not less than 70% and not more than 110%,

(b) the width of the weld metal is not more than 70% of the plate thickness of the base metal, and

(c) the wideness of the region affected by welding whose hardness is softened to not more than 95% of the hardness of the base metal unaffected by heat has a width of not less than 5 mm.

[0020]

(3) A large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, is characterized by:

(a) the hardness of the weld metal is not less than 70% and not more than 110%,

(c) the wideness of the region affected by welding whose hardness is softened to not more than 95% of the hardness of

the base metal unaffected by heat has a width of not less than 5 mm, and

(d) the prior austenite austenite grain size in the heat-affected zone contacting the welding fusion line is not more than 200 μm.

[0021]

(4) A large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, is characterized by:

(a) the hardness of the weld metal is not less than 70% and not more than 110%,

(b) the width of the weld metal is not more than 70% of the plate thickness of the base metal,

(c) the wideness of the region affected by welding whose hardness is softened to not more than 95% of the hardness of the base metal unaffected by heat has a width of not less than 5 mm, and

(d) the prior austenite austenite grain size in the heat-affected zone contacting the welding fusion line is not more than 200 μm.

[0022]

(5) The large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, according to any one of above-described (1) to (4), which is prepared by butt-welding high-strength steel plates over 50 mm in thickness.

[Effect of the Invention]

The present invention forms welded joints with sufficiently high fracture toughness Kc in butt welding high-strength steel plates, in particular high-strength steel plates for welded ship construction, having yield strength of the 460 MPa class and thickness greater than 50 mm.

[Best Mode for Carrying Out the Invention]

[0024]

In order to prevent deformation and stress concentration,

welded joints have conventionally been designed by making the strength and hardness of the weld metal greater than those of the base metal and welding materials whose strength overmatches that of the base metal have been chosen in the design of welded joints.

[0025]

The inventors prepared a steel plate having yield strength of the 460 MPa class and made a welded joint by using a welding material that provides an overmatching weld metal and evaluated the mechanical properties of the welded joint by the deep notch test.

[0026]

Said welded joint showed a sufficiently high value of not less than 90 J at a testing temperature of -20°C and a fairly good structure surface transition temperature of -20°C in the V-notch Charpy test. In the deep notch test, however, fracture toughness Kc was as low as not more than 2,000 $N/mm^{1.5}$. The obtained test result deviated greatly from the conventionally known "interrelation between the result of the V-notch Charpy and deep notch tests".

[0027]

Detailed investigation of the fracture starting points in the deep notch test led to the following findings:

(i) Fracture occurred in the boundary, that is, the fusion line between the weld metal and heat-affected zone (HAZ).

(ii) The microstructure of the region in which fracture started was the same as that of the region in which fracture occurred in the Charpy test specimen.

(iii) The distribution pattern of local stress differs greatly in the deep notch and Charpy tests.

[0028]

The inventors have also made the following finding by analyzing the distribution pattern of local stress that acts as the driving force in the deep notch and Chary tests by three-

dimensional finite element method. That is, the constraining force in the direction of plate thickness increases greatly when the plate thickness exceeds 50 mm and approaches approximately 70 mm and local stress increases greatly at the boundary between the weld metal and heat-affected zone (HAZ) when the strength of the welded metal is greater than the strength of the base metal or heat-affected zone (HAZ). Based on the above analysis, the inventors found that it is necessary to lower the strength of the weld metal as much as possible in order to control the great increase in local stress at the boundary between the weld metal and heat-affected zone.

[0029]

By determining the fracture toughness Kc by varying the hardness of the weld metal (Hv(WM)) based on the result of the above analysis and plotting the values Kc vs. the "hardness of the weld metal [Hv(WM)]/hardness of the base metal [Hv(BM)], it was found that the lowering of fracture toughness due to the increase in local stress can be prevented by controlling the hardness of the metal [Hv(Mw)] to not more than 110% of the hardness of the base metal [Hv(MN)], as indicated by "●" in Fig. 1.

[0030]

It was discovered that it is necessary for increasing the fracture toughness of welded joint to make the hardness of the weld metal lower than the hardness of the base metal. If, however, the hardness of the weld metal is lowered, the strength (tensile strength) of welded joints decreases to such levels as will cause fatal problems in structures.

[0031]

So, the lower limit of the weld metal strength required for securing as much strength as that of the base metal in welded joints was empirically studied. Then, it was found that adequate strength (tensile strength) can be secured in welded joints even if the hardness of the weld metal drops to 70% of the hardness of the base metal if the width of the weld metal

(bead width) is limited to not more than 70% of the plate thickness in the region where the width of the weld metal (bead width) has a great effect, as shown in Fig. 2.

[0032]

In order to secure the desired fracture toughness Kc in welded joints, it is necessary to insure that local stress does not increase along the fusion line (FL) that is the weakest pats of the welded joint, as mentioned earlier. At the same time, it is also important to enhance the microstatic brittle fracture resistance in and around the fusion line (FL).

[0033]

Studies on mechanism that create brittle fracture in the vicinity of the fusion line (FL) led to a finding that keeping the grain size of prior austenite small is conducive to improving the brittle fracture resistance because the pro-eutectoid ferrite in the vicinity of prior austenite and lath-like upper bainite and ferrite side plate in prior austenite become the starting point of fracture.

[0034]

The result of the experiment conducted by the inventors indicates that it is preferable to keep the prior austenite grain size in the heat-affected zone (HAZ) contacting the fusion line (FL) at or below 200 μm.

[0035]

The inventors also discovered that the occurrence and distribution of local stress along the fusion lie (FL) in contact with the weld metal is governed by the hardness of the weld metal and there is a tendency that the local stress along the fusion line (FL) is lessened if the heat-affected zone (HAZ) in contact with the fusion line (FL) has a large "softened region".

[0036]

It is preferable to insure that the softened region in the heat-affected zone (HAZ) is not less than 5 mm in width as said lessening was observed when the width of the softened region in

the heat-affected zone (HAZ) was not less than 5 mm in the experiment conducted by the inventors. In principle, local stress decreases if the hardness of the heat-affected zone (HAZ) is lower than the hardness of the base metal. In the experiment conducted by the inventors, local stress decreased definitely when the hardness of the heat-affected zone (HAZ) was lower than the hardness of the base metal by not less than 5%.

[0037]

Therefore, it is preferable to insure that the region of the heat-affected zone that is softened to not more than 95% of the hardness of the base metal unaffected by heat has a width not smaller than 5 mm.

[0038]

The high-structure plates for welded structures and ship shells used with the present invention can be manufactured from structural steels for welding purposes of known compositions. Preferable steels are, for example, those comprising, by mass%, C of 0.02 to 0.20%, Si of 0.01 to 10%, Mn of 0.3 to 2.0%, Al of 0.001 to 0.20%, N of not more than 0.02%, P of not more than 0.01%, S of not more than 0.01%, and containing one or more of N, Cr, Mo, Cu, W, Co, V, Nb, Ti, Zr, Ta, Hf, REM, Y, Ce, Ca, Mg, Te, Se and B, as required for the enhancement of base metal strength, joint toughness and other properties.

[0039]

While thickness of plates is not specifically limited, it is preferable to apply the present invention to, for example, high-strength steel plates, for large ship shells, exceeding 50 mm in thickness.

[0040]

Chemical composition of the welding material used in the present invention is not specifically limited so long as the hardness of the weld metal specified by the present invention is obtained. While it is preferable that welding materials comprise C of 0.01 to 0.06%, Si of 0.2 to 1.0%, Mn of 0.5 to

2.5%, Ni of not more than 4.0%, Mo of not more than 0.30%, Al of not more than 0.3%, Mg of not more than 0.30%, Ti of 0.02 to 0.25% and B of not more than 0.050%, choice can be made as appropriate by considering the chemical composition of the steel plate.

[0041]

Welding methods are not particularly limited so long as the width of the weld beads (weld metals) width specified by the present invention can be obtained, and conventional electro gas welding (EG), double electrode oscillating electrode gas welding (VEGA-II) or arc welding such as CO_2 welding can be used. Laser welding and electron beam welding, which can easily control the width of the weld beads, are within the scope of the present invention so long as the hardness of the weld metal is controlled using a welding material.

[0042]

Welding methods that do not use welding materials tend to make the hardness of the weld metal greater than the hardness of the base metal because the weld metal is formed by the melting and solidification of the base metal. Therefore, such welding methods are not preferred in view of control of the hardness of the weld metal.

[Example]

[0043]

The present invention is now described by reference to an example tested under the conditions employed to confirm the practicability and effect of the invention. The present invention is not limited to said conditions.

[0044]

The present invention can be practiced under various conditions and combinations thereof without departing from the scope and spirit of the invention so long as the object of the invention is achieved.

[0045]

(Example 1)

Characteristics and performances of welded joints were tested and investigated by using steel plates 55 to 100 mm in thickness. Table 1 shows the results.

[0046]

Welding was performed by VEGA-II (double electrode oscillating electro gas welding), EG (electro gas welding) and SAW (submerged arc welding). The respective conditions are shown in Table 2.

[0047]

The groove angle and root gap were 20° V groove and 8 mm in VEGA-II and EG, and 40° Y groove and 2 mm in SAW.

[0048]

The hardness of the base metal [Hv(BM)] is the average hardness across the thickness of the steel plate that was determined by pressing a 10 kg indenter therein. The hardness of the base metal [Hv(BM)] is the hardness of the weld metal determined by pressing a 10 Kg indenter at the center of the thickness of the weld metal.

[0049]

The bead width is the average of the values measured at the front and back sides and the center of the thickness of the weld metal.

[0050]

The width of the softened region in the heat-affected zone (HAZ) is the width of the region extending from the fusion line toward the base metal in which hardness softens by 5% from the hardness of the base metal.

[0051]

The prior austenite grain size in the heat-affected zone (HAZ) is that in the heat-affected zone (HAZ) in contact with the fusion line expressed in terms of equivalent diameter.

[0052]

The fracture surface transition temperature vTrs (°C) was determined by varying the testing temperature applied on the test specimens that were prepared so that the fusion line (FL),

which is the weaker part of the welded joint, is at the center of the thickness thereof.

[0053]

The fracture toughness Kc ($N/mm^{1.5}$) was determined by said deep-notch test at -20°C. The values with the [>] mark indicate that, despite the trace of ductile cracks resulting from sufficient deformation of the notch in the test specimen, the specimen width of 400 mm inhibited further measurement of the Kc value.

[0054]

The tensile strength of the welded joint (MPa) indicates the strength at which the NKU No. 1 test specimen fractured in the joint tensile test.

[0055]

As shown in Table 1, test specimens Nos. 1 to 14 according to the present invention showed sufficient fracture toughness Kc and joint strength because all conditions are within the ranges specified by the invention.

[0056]

In contrast, specimens Nos. 15 to 17 tested for comparison showed low Kc as, despite that vTrs in the Sharpy test is substantially equal to those of specimens Nos. 1 to 14 according to the present invention, because the Hv(WM)/Hv(BM) exceeds the upper limit specified by the present invention.

[0057]

The specimen No. 18 tested for comparison showed a sufficient Kc value because the Hv(WM)/Hv(BM) is less than the lower limit specified by the present invention and therefore vTrs in the Sharpy test is substantially equal to those of specimens Nos. 1 to 14 according to the present invention. However, the specimen No. 18 tested for comparison showed low joint strength.

[0058]

Specimens Nos. 19 and 20 tested for comparison showed low joint strength because the bead width exceed the upper limit

specified by the present invention.

[0059]

[Table 1]

	No.	Butt-Welded Joint				Characteristics of Welded Joint					
		Type of Steel	Plate Thickness (mm)	Welding Method	Welding Condition	Hv(BM)	Hv(WM)	Hv(WM)/Hv(BM)	Bead width/Plate thickness	Width of Softened Region in HAZ (mm)	Prior austenite Grain Size in HAZ (μm)
Specimens of the present invention	1	YP47	70	VEGA-II	V3	202	212	1.05	0.45	12	180
	2	YP47	70	EG	E3	204	200	0.98	0.67	15	190
	3	YP47	65	EG	E2	210	151	0.72	0.66	13	170
	4	YP47	70	VEGA-II	V3	205	226	1.1	0.51	15	150
	5	YP47	70	VEGA-II	V3	220	233	1.06	0.4	18	165
	6	YP47	60	VEGA-II	V2	215	204	0.95	0.46	16	175
	7	YP47	55	VEGA-II	V1	210	208	0.99	0.61	7	55
	8	YP47	70	VEGA-II	V1	200	206	1.03	0.45	17	120
	9	YP47	55	SAW	S1	195	205	1.05	0.68	8	45
	10	YP47	65	SAW	S2	210	227	1.08	0.5	11	58
	11	YP47	75	SAW	S3	204	222	1.09	0.67	8	75
	12	YP47	80	VEGA-II	V4	206	150	0.73	0.4	12	280
	13	YP47	100	VEGA-II	V5	210	200	0.95	0.35	13	190
	14	YP47	55	SAW	S1	210	208	0.99	0.61	3	55
Specimens for Comparision	15	YP47	70	VEGA-II	V3	202	265	*1.31	0.45	12	180
	16	YP47	70	EG	E3	204	235	*1.51	0.67	15	190
	17	YP47	85	EG	E2	210	258	*1.23	0.66	13	170
	18	YP47	70	EG	E3	205	133	*0.65	0.51	15	150
	19	YP47	70	EG	E3	220	224	1.02	*1.2	18	165
	20	YP47	60	EG	E1	215	204	0.95	*0.8	16	175

Table 1 (Continued)

	No.	Performance of Welded Joint		
		vTrs in Charpy Test	Kc ($N/mm^{1.5}$)	Tensile Strength of Joint (MPa)
Specimens of the present invention	1	-5	4980	610
	2	-10	>5200	602
	3	-1	4200	590
	4	-3	4890	620
	5	-25	>5100	615
	6	2	4100	623
	7	-30	>5100	598
	8	-3	4230	602
	9	-15	5100	620
	10	-23	>5100	615
	11	-10	4850	610
	12	3	4100	590
	13	-8	4250	610
	14	-25	3520	598
Specimens for Comparision	15	-4	*980	610
	16	-12	*1500	602
	17	-5	*950	590
	18	-6	4720	*502
	19	-28	>5100	*490
	20	-10	4100	*520

The symbol "*" denotes the value which is not within the scope of the present invention.

[0060]

[Table 2]

Welding Method		Welding Condition	Plate Thickness (mm)	Current I(A)		Voltage E(V)	Welding Speed V(cm/min)	Heat Input (KJ/cm)	Wire Diameter (mm)
VEGA-II		V1	55		420	42	6.5	326	1.6
		V2	60		420	42	6.0	353	1.6
		V3	70		420	42	4.5	470	1.6
		V4	80		420	42	4.0	529	1.6
		V5	100		420	44	3.5	664	1.6
EG		E1	60		420	42	3.0	353	1.6
		E2	65		420	42	2.5	423	1.6
		E3	70		420	42	2.1	504	1.6
SAW	Single pass welding	S1	55	Advance	2100	42	18	571	6.4
				Post	1600	52			6.4
	Seven pass welding	S2	65	Advance	1400	37	40	159	6.4
				Post	1200	45			6.4
		S3	75	Advance	1400	37	35	181	6.4
				Post	1200	45			6.4

[Industrial Applicability]

[0061]

The present invention prevents fatal damage and fracture of welded structures because brittle fracture hardly occurs in large-heat-input welded joints of thick high-strength steel plates even when there are some welding defects and fatigue cracks occur and develop.

[0062]

Thus, the present invention, that significantly enhances the safety of welded structures, has a great industrial applicability.

[Brief Description of the Drawings]

[0063]

Fig. 1 shows the effect of the hardness of the weld metal and base metal on a Kc value.

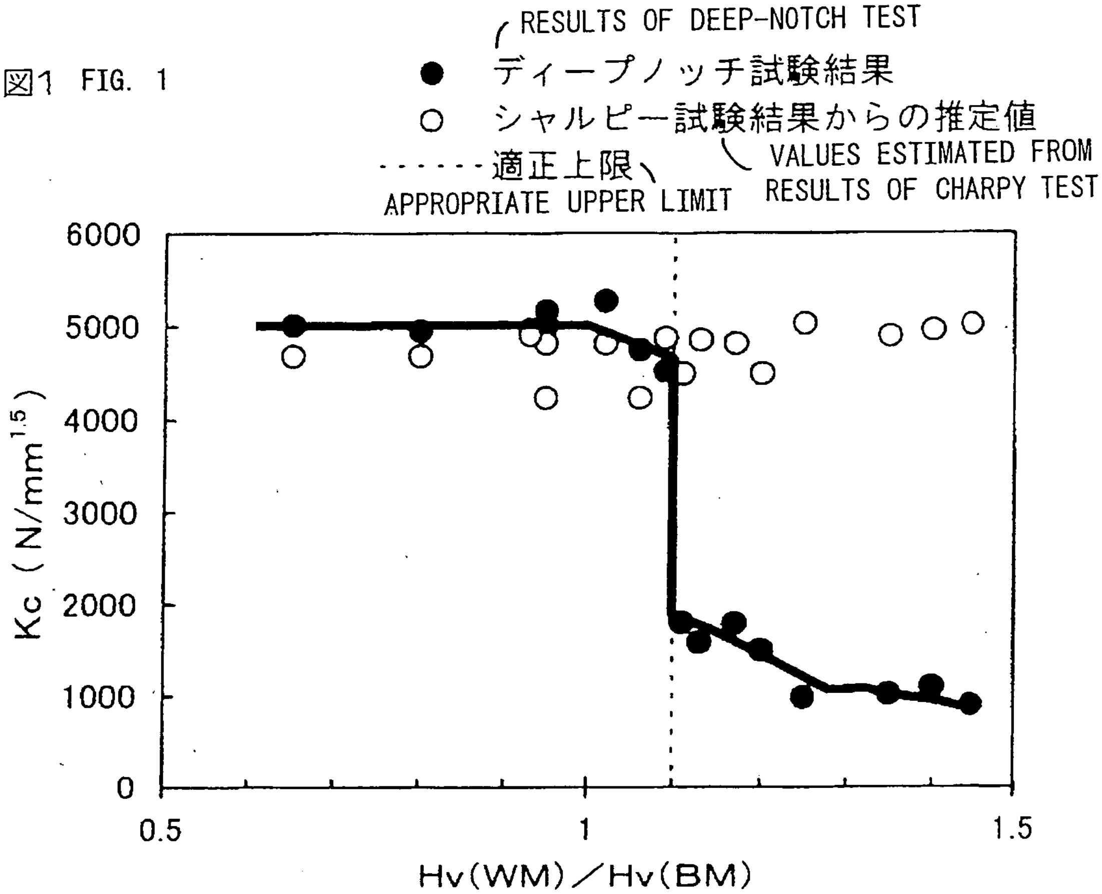
Fig. 2 shows the relationship between the hardness ratio between the weld metal and base metal, bead width and joint strength.

【書類名】図面 [NAME OF DOCUMENT] DRAWINGS

【図1】

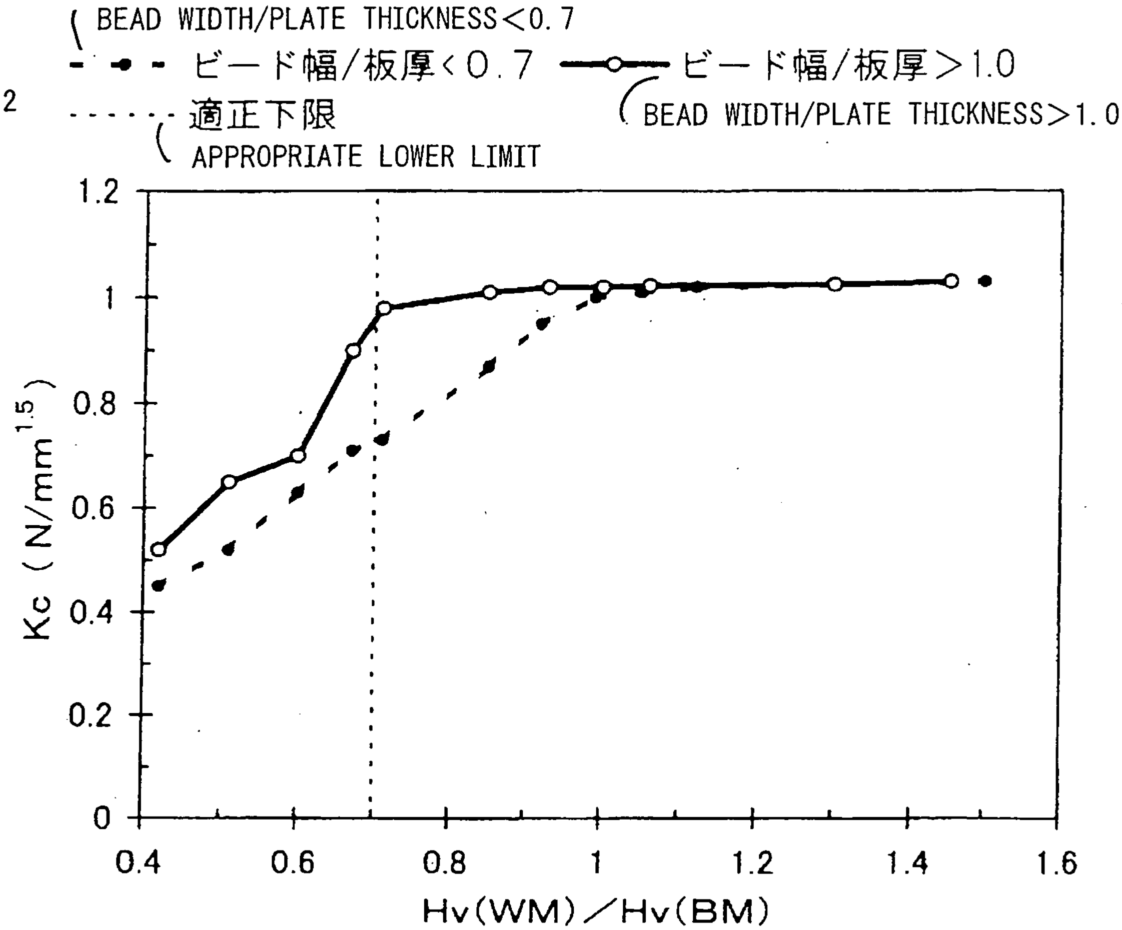
[FIG. 1]

図1 FIG. 1



【図２】
[FIG. 2]

図２
FIG. 2



[NAME OF DOCUMENT] Abstract

[ABSTRACT]

[OBJECT] To provide weld joints having sufficiently high fracture toughness Kc by butt welding high-strength steep plates for welded ship construction having yield strength of the 460 MPa class and thickness greater than 50 mm.

[SOLUTION MEANS] A large-heat-input butt-welded joint of welded structures, having excellent brittle fracture resistance, is characterized by:(a) the hardness of the weld metal is not less than 70% and not more than 110%, (b) the width of the weld metal is not more than 70% of the plate thickness of the base metal and, optionally, (c) the wideness of the region affected by welding whose hardness is softened to not more than 95% of the hardness of the base metal unaffected by heat has a width of not less than 5 mm, and/or (d) the prior austenite austenite grain size in the heat-affected zone contacting the welding fusion line is not more than 200 μm.

[SELECTED DRAWING] Fig. 1